ULTRA VIOLET RAYS; THEIR ADVANTAGES AND DISADVANTAGES IN THE PURIFICATION OF DRINKING WATER[1]

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The purification of drinking water on a large scale has always been a problem of greatest moment to sanitarians and public hygienists. None of the present accepted methods has a general application, but in each case an appropriate method must be chosen which can be operated efficiently and economically. In the application of ultra violet rays to the purification of water the limitations of the method must be particularly considered. On the other hand, in view of the well established bactericidal property of these rays and the results of certain tests, hereinafter tabulated, on two types of ultra violet ray apparatus at the laboratory of the Sanitary District of the Great Lakes, it is believed that this method of purifying drinking water will give satisfactory results, under suitable conditions.

Properties of ultra violet rays. The ultra violet rays, which are present to a greater or less extent in all light, are invisible rays, lying beyond the violet end of the spectrum.

In 1877, Downes and Blunt (1) showed that sunlight was an efficient bactericidal agent. In 1892 Marshall Ward (2) by analyzing the effect of the spectrum thrown on infected agar plates demonstrated that the bactericidal action "begins at the blue end of the green and rises to a maximum as we pass to the violet end of the blue." He further observed that the bactericidal activity extended far into the ultra violet when the light passed only through quartz. Following these observations considerable attention was given to the physiological effect of light. The ordinary phenomenon of sunburn was shown to be due to the actinic or chemical rays and not to the caloric rays, as was formerly thought. Finsen (3) has obtained very excellent results by using the chemical rays of light in the treatment of skin diseases.

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Of all the spectral rays the ultra violet is the most refrangible; at the same time it possesses the strongest chemical effect and the least heating effect. The other extremity of the spectrum presents the opposite phenomenon. The red and infra-red are the least refrangible and the chemical effect is at a minimum. The visible rays of the spectrum are those that have wave lengths between 0.76 micron and 0.4 micron. Both the ultra violet and the infra-red rays lie outside of these limits of visibility (infra-red wave lengths are between 300 and 0.76 microns; ultra violet rays are between 0.4 and 0.1 micron). The ease with which these rays of short-wave lengths are absorbed is quite characteristic. Ultra violet rays are absorbed by nearly all material, except fused rock crystal (quartz), fluor spar, a specially prepared glass called Uviol, air and water. Even these interrupt part of the rays; for example, several centimeters of air absorb completely the wave lengths below 0.185 micron while quartz absorbs the wave lengths below 0.2 micron. Besides their bactericidal or abiotic power, as it has been called, ultra violet rays are capable of accelerating many chemical reactions, and in this instance apparently act as a catalytic agent. For example, chlorine and hydrogen, which combine slowly in diffuse light, combine with an explosion under the influence of ultra violet rays. White phosphorus is changed into the amorphous form (red phosphorus). Ozone is produced in air. Hydrogen peroxide is formed in clear water. The blackening of photographic paper is due almost entirely to the chemical rays. In handling this material it is exposed only to a red light, which holds back the shorter waves and allows only red and infra-red to pass. Commercially the ultra violet rays are used to detect willemite ($2ZnO$, SiO_2), a zinc ore in furnace tailings (4). This substance has a peculiar luminous glow when exposed to the ultra violet rays. Further, it is claimed ultra violet rays have the power of bleaching linseed oil, ripening the pods of vanilla beans, destroying or attenuating the action of ferments, and hydrolysing saccharose.

Measurement of rays. Up to this time no satisfactory method has been devised by which ultra violet light can accurately be measured. Since the rays are invisible the amount of radiation can only be estimated by noting their physical or chemical effect on various substances. The amount of fluorescence produced on certain compounds, the speed with which photographic paper is blackened and the decomposition of various chemicals are all methods which

may be employed for determining the ultra violet "candle power" of a lamp. Probably the most reliable method is the determination of the bactericidal power of a lamp. Von Recklinghausen (5) has recommended that "a standard source of ultra violet light composed of a certain lamp which is so kept that it is unlikely to change the candle power, be compared with the action of the lamp one wants to measure on one and the same culture of germs." He used a culture of paramecium. A drop of such a cuture is exposed at a definite distance from the laboratory standard quartz lamp and another drop at the same distance from the lamp to be tested. By recording the time necessary for killing, the relative value of the two lamps can be obtained. However, it has not been determined that bactericidal activity and chemical activity of the rays are proportional. This relation could probably be determined easily, and if found, might lead to more accurate quantitative determinations by means of chemical effects. Such quantitometric determinations would be much simpler in technic than the biological method.

Mercury vapor arc lamp. The richest known artificial source of ultra violet rays is the mercury vapor arc inclosed in a quartz tube. The principal advantage of this arc lamp over other lamps is the fact that no disintegration of the electrodes occurs. When the lamp is lighted, the electrodes are constantly being replaced by the condensed mercury vapor running back to the electrode container. The light is made by tilting the lamp so that the mercury forms a complete bridge from one electrode to the other, and then on releasing the tube the mercury runs back and draws out the arc. The lamp cannot run on alternating current because as soon as the value of the current sinks to zero the arc goes out and cannot restart except by re-striking. The life of such a lamp is stated to be from 1500 to 7000 hours. The production of ultra violet rays increases with the temperature of the lamp. Consequently, when first lighted the yield is small and a maximum is not reached for five or ten minutes.

Use in water purification. The first practical results in purifying drinking water with this light were obtained by Courmont and Nogier (6). They suspended their lamp in a metallic tank and with both naturally and artificially polluted water, obtained complete sterility in one to two minutes. The following year, Henri, Helbronner and von Recklinghausen (7) made experiments with water flowing at

125 cubic meters, or 33,000 gallons, per hour. Water polluted artificially with a rich emulsion of B. coli was passed through the fields of four lamps arranged in series. The samples taken beyond the second lamp were sterile. Bacterial spores, also, were found to be killed but showed considerably more resistance than vegetative forms.

At the present time this method is receiving considerable appli-

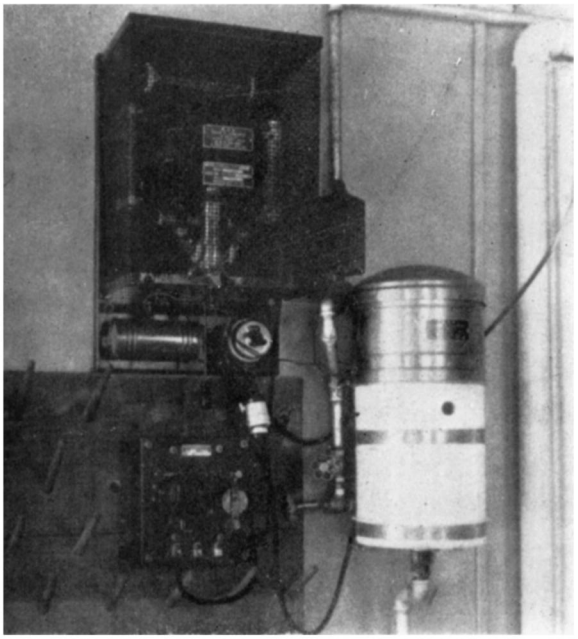

FIG. 1. ULTRA VIOLET RAY STERILIZING APPARATUS OF THE GRAVITY TYPE

Equipped with automatic tilted lamp and solenoid operated water valve so arranged that no water can pass the apparatus unless the current is on and the lamp at its maximum intensity.

cation in furnishing treated water for drinking purposes, in bottling works, in the sanitation of swimming pools, and for the use of armies in the field. In France the method is said to be successfully applied to the treatment of municipal water supplies.

Owing to the fact that ultra violet rays are readily absorbed by many organic substances and that their penetration into the water is hindered by the presence of suspended matter, it is necessary that

the water be perfectly clear, prior to treatment. For the purpose of removing turbidity, a rapid sand filter is usually employed.

Description of apparatus tested, with results. A gravity and a pressure type of apparatus were tested, Figs. 1 and 2. In the gravity type the lamp is suspended in a baffled treatment chamber a few inches above the surface of the water, which in a thin film is exposed twice during its passage by the lamp. This type is operated at 110 volts, and has a rated capacity of 120 gallons per hour.

The pressure type consists of a cast iron cylindrical shell with a quartz tube through its axis and containing an arrangement of

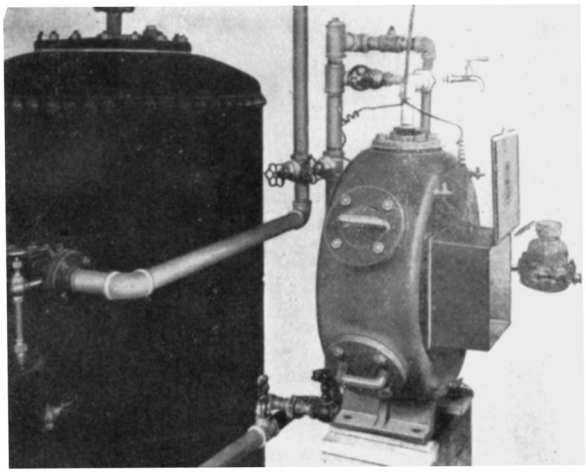

FIG. 2. LARGE PRESSURE TYPE ULTRA VIOLET RAY STERILIZING APPARATUS

Showing rapid sand filter, sampling cocks and water meter for measuring the rate of flow.

baffle plates for the same purpose as those in the gravity type. The lamp is inserted within the axial quartz tube. A 220-volt lamp is required to produce a sufficient amount of ultra violet rays for treating 750 gallons of water per hour, the rated capacity.

Usually a fluctuation in voltage of 10 per cent or over is sufficient to extinguish the light. To prevent the passage of untreated water, each apparatus is provided with an automatic electrical arrangement controlling a solenoid valve which will prevent the flow of water until the temperature of the lamp has risen sufficiently to produce

an abundance of ultra violet rays and which will cut it off when for any reason the light goes out.

Each apparatus was operated in connection with a rapid sand pressure filter which clarified the water just before it entered the light chamber. It was at this point that all the raw water control samples were taken. In order to artificially contaminate the water, the alum shunt-feed box on the filter was kept filled with rich broth cultures of B. coli and other bacteria. By this means enormous quantities of all kinds of organisms could be fed to the filter, which allowed nearly all to pass through to the ultra violet ray apparatus after the sand bed had once become thoroughly saturated with them. It can be seen from the accompanying tables that the raw water contained many times more B. coli than one ever finds in the worst drinking water.

The vast majority of all samples were collected while the apparatus was being operated in excess of its rated capacity.

The following table includes a total of 142 samples taken on 17 different days during a period of two months, with a small gravity type apparatus having a capacity of 120 gallons per hour.

NUMBER AND KIND OF SAMPLE	AVERAGE TOTAL COUNT PER CC. ON AGAR AT 37° C.	AVERAGE NUMBER OF B. COLI
33 raw water	29,400	3.256 in 1 cc.
109 treated water	12	1 B. coli in 15 cc.

86 of 109 treated samples gave 0 B. coli in 50 cc.
10 of 109 treated samples gave 1 B. coli in 50 cc.
2 of 109 treated samples gave 2 B. coli in 50 cc.
2 of 109 treated samples gave 3 B. coli in 50 cc.
1 of 109 treated samples gave 4 B. coli in 50 cc.
1 of 109 treated samples gave 5 B. coli in 50 cc.
7 of 109 treated samples gave 50 B. coli in 50 cc.

The last seven samples showing 50 B. coli in 50 cc. were taken after the machine had been idle for one month and the raw water controls at the same time had at least 100,000 B. coli per cubic centimeter and a total count of 150,000. If these seven samples are eliminated in figuring the average number of B. coli in the treated water, there would be only one B. coli in 175 cc. instead of one in 15 cc. as shown in the table.

One day's test on small gravity-type apparatus

LOCATION	HOUR	BACTERIA ON AGAR AT 37° C.			B. COLI IN LACTOSE BROTH												RATE GALLONS PER HOUR
		Plate 1	Plate 2	Average	0.0001 cc.		0.001 cc.		0.01 cc.		0.1 cc.		1 cc.		10 cc.		
					G	E	G	E	G	E	G	E	G	E	G	E	
F	10:20	48,000	53,000	50,500	+	+	+	+	+	+	+	+	+	+	+	+	105
S	10:20	4	0	2							0		0		0		105
S	10:25	2	2	2							0		0		0		105
S	10:30	3	3	3							0		0		0		105
S	10:35	4	2	3							0		0		0		105
S	10:40	1	3	2							0		0		0		105
S	10:45	7	9	8							0		0		0		135
S	10:50	6	8	7							0		0		0		135
S	10:55	7	10	8.5							0		0		0		135
S	11:00	6	13	9.5							0		0		0		135
F	11:00	51,000	50,000	50,500	+	0	+	+	+	+	+	+	+	+	+		135

F = filter sample; G = gas on lactose broth; S = sterilized sample; E = confirmation on endo media.

Apparatus ran fifteen minutes before first sample was taken.

The following table includes a total of 330 samples taken on 29 different days during a period of two months, with a pressure-type apparatus having a capacity of 750 gallons per hour.

NUMBER AND KIND OF SAMPLE	AVERAGE TOTAL COUNT PER CC. ON AGAR AT 37° C.	AVERAGE NUMBER OF B. COLI
48 raw water	3,900	2,630 in 1 cc.
282 treated water	7	1 B. coli in 103 cc.

211 of 282 treated samples gave 0 B. coli in 50 cc.
31 of 282 treated samples gave 1 B. coli in 50 cc.
21 of 282 treated samples gave 2 B. coli in 50 cc.
14 of 282 treated samples gave 3 B. coli in 50 cc.
3 of 282 treated samples gave 4 B. coli in 50 cc.
2 of 282 treated samples gave 5 B. coli in 50 cc.

One day's test on large pressure-type apparatus

LOCATION	HOUR	BACTERIA ON AGAR AT 37° C.			B. COLI IN LACTOSE BROTH												RATE GALLONS PER HOUR
		Plate 1	Plate 2	Average	0.0001 cc.		0.001 cc.		0.01 cc.		0.1 cc.		1 cc.		10 cc.		
					G	E	G	E	G	E	G	E	E	G	G	E	
F	10:10	4800	4500	4650	0		+	+	+	+	+	+	+	+	+	+	1270
S	10:10	0	0	0							0		0		0		1270
S	10:15	0	2	1							0		0		0		1270
S	10:20	1	0	½							0		0		0		1270
S	10:25	1	0	½							0		0		0		1270
S	10:30	3	1	2							0		0		+	0	1270
S	10:35	0	1	½							0		0		0		1270
S	10:40	2	0	1							0		0		0		1270
S	10:45	3	0	1½							0		0		0		1270
S	10:50	0	0	0							0		0		0		1270
S	10:55	1	2	1½							0		0		0		1270
S	11:00	1	2	1½							0		0		0		1270
S	11:05	0	0	0							0		0		0		1270
S	11:10	1	0	½							0		0		0		1270
F	11:10	3200	3700	3450	0		0		0		+	+	+	+	+	+	1270

F = filter sample; S = sterilized sample; G = gas on lactose broth; E = confirmation on endo.

The apparatus ran fifteen minutes before the first sample was taken.

The bacteriological tests were performed, with slight exception, in accordance with the Standard Methods of Water Analysis of the American Public Health Association. The fermentation of lactose broth and the characteristic appearance on Endo were considered sufficient identification of B. coli.

A total of 391 treated samples were tested. Of these 53, or 13.5 per cent, did not come within the Treasury Department standard of permissible impurity, which requires that not more than one of five 10-cc. portions of each sample shall show the presence of organisms of the B. coli group. This appears to be a poor showing. However, it cannot be so considered when a comparison is made with the extremely polluted raw water control samples collected at the same time.

In the gravity type of apparatus 86 of 109 treated samples, or 78.8 per cent, showed no organisms of the B. coli group in 50 cc., while the untreated water contained an average of 3256 B. coli per cubic centimeter.

In the pressure type 211 of 282 treated samples, or 74.8 per cent, gave no B. coli in 50 cc. while the untreated water was yielding 2630 B. coli in 1 cc. The great reduction is the more remarkable when one considers that the actual time of exposure of the water to the rays is approximately sixty-four seconds in the large, and thirty seconds in the small apparatus, when they are running at their normal rate.

The fact that spore bearing organisms are somewhat more resistant to these rays than vegetative forms, has been shown by von Recklinghausen. In the above outlined tests the lactose broth tubes would frequently show fermentation at the end of forty-eight hours. In such cases transfers invariably proved negative on Endo for B. coli. The organism that caused this result proved to be a strict anaerobe and was later identified as belonging to the B. Welchi group. It is believed that the appearance of such organisms in water is not of sanitary significance (14).

Conclusions. The use of ultra violet rays in the purification of drinking water is relatively a recent procedure, and it is believed that the method is capable of further development, with a corresponding increase in efficiency. The method is especially recommended for treating water in circulating systems, in which the water may be exposed many times to the ultra violet rays. Such systems are now used for disinfecting water in swimming pools, hotels, industrial, and other institutions. The chief advantages of this method of treatment over chemical methods lies in the fact that objectionable overdosage is impossible. Again, from the standpoint of potability, the water is absolutely unchanged, and hence, in this respect, is superior even to boiled water. Recently, ultra violet rays have been recommended for sterilizing the drinking water on vessels traversing the Great Lakes (15). The fresh water of the lakes is very clear, and the turbidity that does occasionally occur consists mostly of heavy suspended matter and is easily removed by filtration.

The present forms of apparatus need considerable attention when in operation. Care should be taken to prevent an accumulation of grease or dirt of any kind on the quartz tube. Experience has shown that a very small amount of grease will obstruct the light sufficiently to allow many organisms to pass. Furthermore, the light chamber should be emptied if the machine remains idle for any length of time. This will prevent the growth of algae and other

organisms which will obstruct the light when the machine is again operated. The latest types of apparatus are now arranged so that the quartz tube can easily be removed for inspection and cleaning. There is no way to determine when the lamp fails to emit a sufficient amount of ultra violet rays to give a maximum bactericidal effect, except by collecting samples and testing the treated water frequently. Theoretically, as long as the lamp remains intact and the vacuum holds, no reduction in the amount of ultra violet emanation occurs. It is stated by the manufacturers that a lamp will wear out before its efficiency noticeably decreases. The proper construction of the lamp, however, is of great importance and considerable variations have been noted between individual lamps.

In the above tests, since the gravity type gave a higher efficiency than the pressure type, and inasmuch as any lamp operating at a higher voltage is known to emit a larger amount of ultra violet radiation, the use of lamps at a higher voltage, combined with the gravity system, suggests itself as a reasonable line of development.

In regard to cost, the method is not expensive when treating relatively small quantities of water. For municipal supplies, using several million gallons per day, the expense is considerable, and probably prohibitive. The larger passenger vessels on the Great Lakes, which need a maximum of 25,000 to 30,000 gallons per day, have found the use of ultra violet to be the most economical method which meets the Government requirements for drinking water supplied to passengers in interstate traffic.

Up to the present time this method of treating water has not been applied very extensively; nor has it been developed to the extent that the known evidence in its favor would seem to indicate.

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